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Zhu et al.

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(54) **PRINTED PHYSICAL UNCLONABLE FUNCTION PATTERNS**

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(51) **Int. Cl.**

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G06F 18/00	(2023.01)
G06K 1/12	(2006.01)
G06K 19/06	(2006.01)
H04L 9/32	(2006.01)

(52) **U.S. Cl.**

CPC ***G06V 10/757*** (2022.01); ***G06F 18/00*** (2023.01); ***G06K 1/121*** (2013.01); ***G06K 19/06028*** (2013.01); ***G06K 19/06037*** (2013.01); ***G06V 10/751*** (2022.01); ***H04L 9/3278*** (2013.01)

(58) **Field of Classification Search**

CPC B41M 3/14; B42D 25/346; B42D 25/36; B42D 25/378; G06F 18/00; G06K 1/121; G06K 19/06028; G06K 19/06037; G06V 10/751; G06V 10/757; H04L 9/3278

See application file for complete search history.

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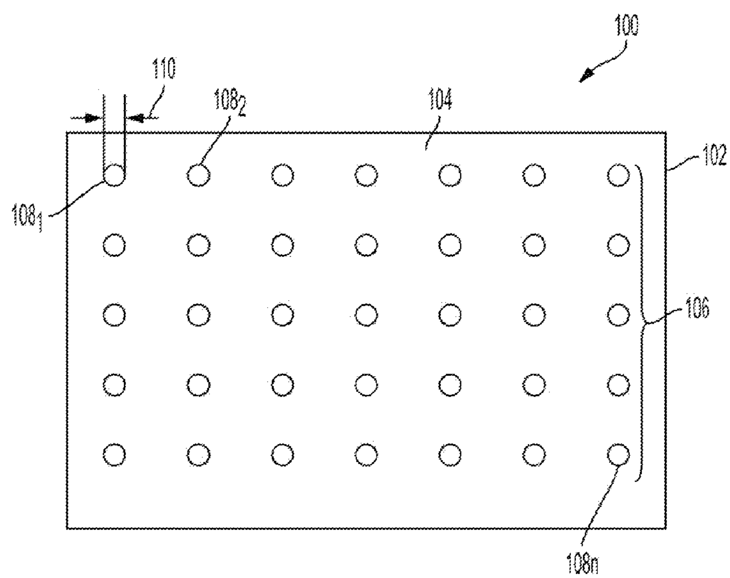
(57) **ABSTRACT**

A method is disclosed. For example, the method includes applying a clear coat layer on a substrate, drying the clear coat layer to form random microstructures in the clear coat layer, dispensing a printing fluid to print a graphical pattern on the clear coat layer, and generating a physical unclonable function (PUF) pattern by drying the printing fluid that fills the random microstructures formed in the clear coat layer.

17 Claims, 7 Drawing Sheets



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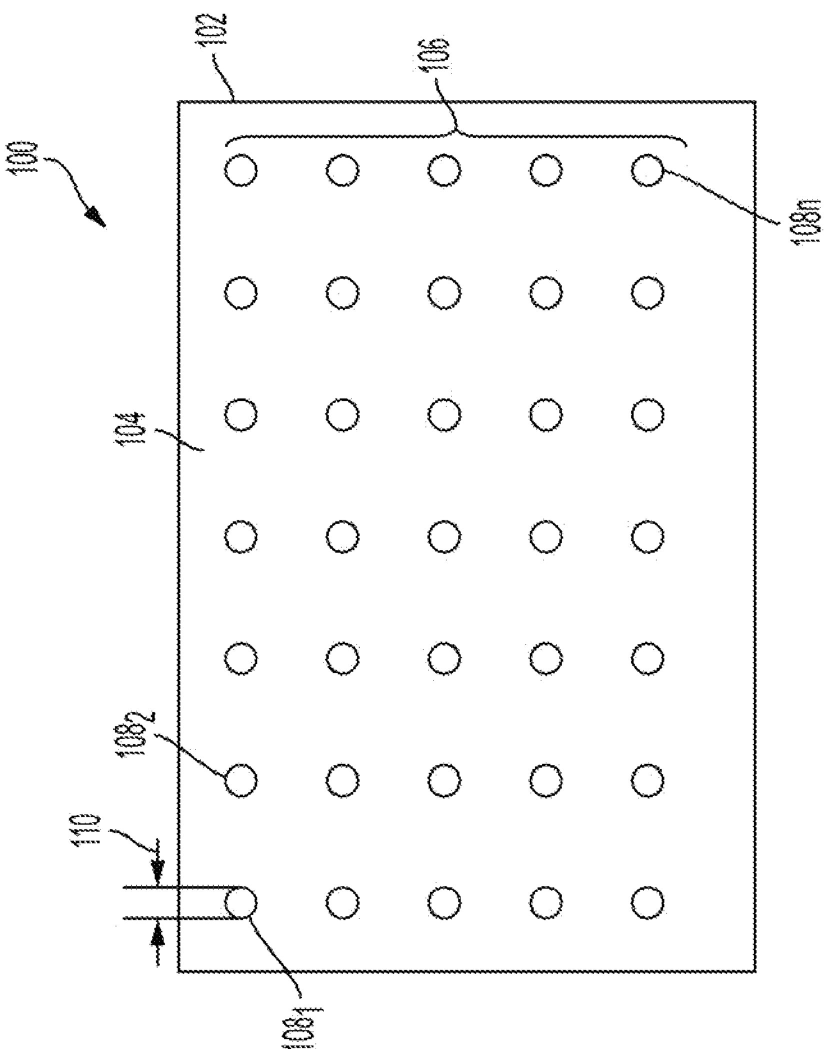

FIG. 1

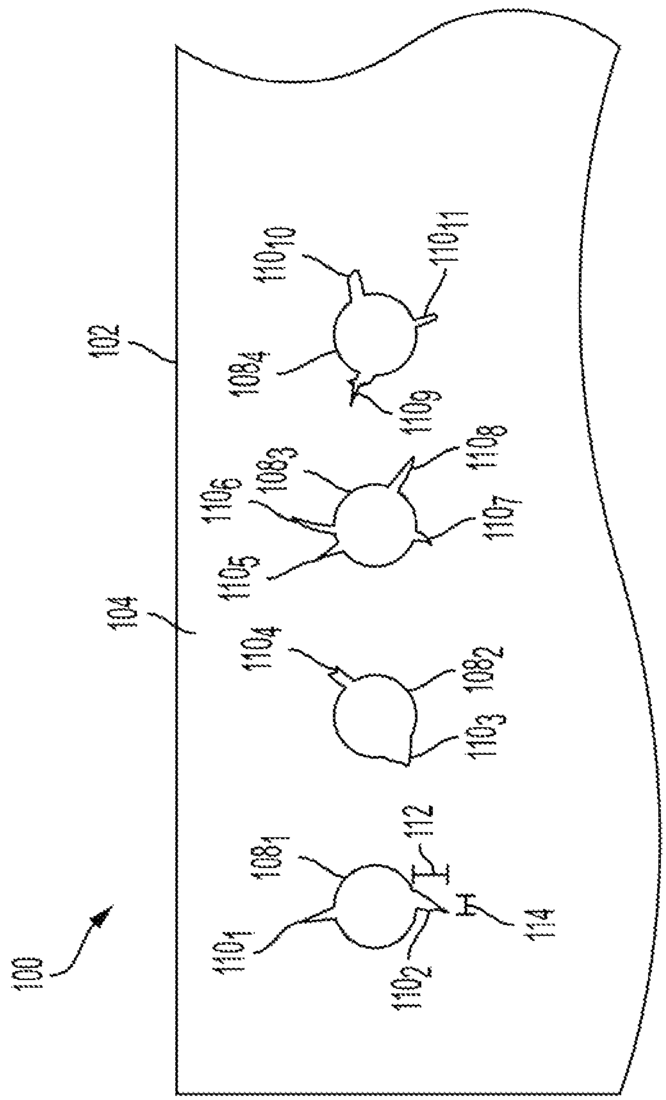
100
102
104
108_1
108_2
108_3
108_4
110_1
110_2
110_3
110_4
110_5
110_6
110_7
110_8
110_9
110_{10}
110_{11}
112
114

FIG. 2

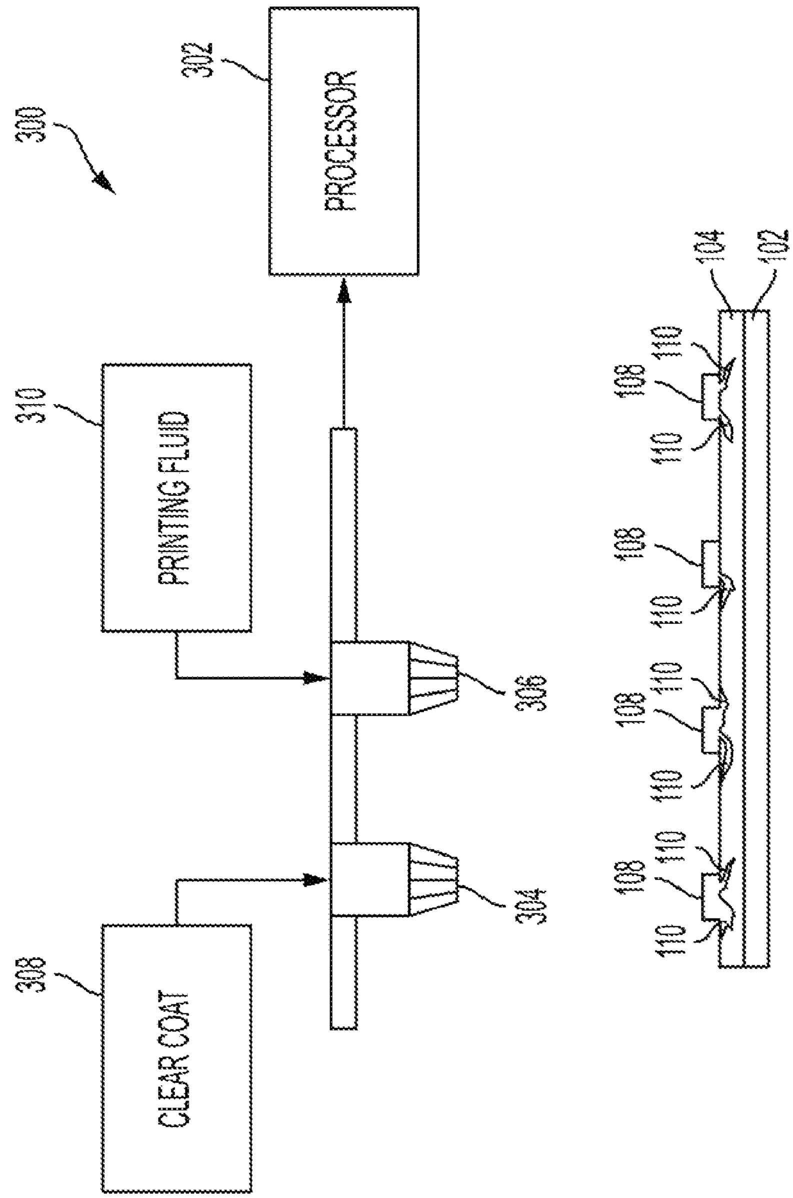
300
302
PROCESSOR
310
PRINTING FLUID
308
CLEAR COAT
306
304
104
102
108
110

FIG. 3

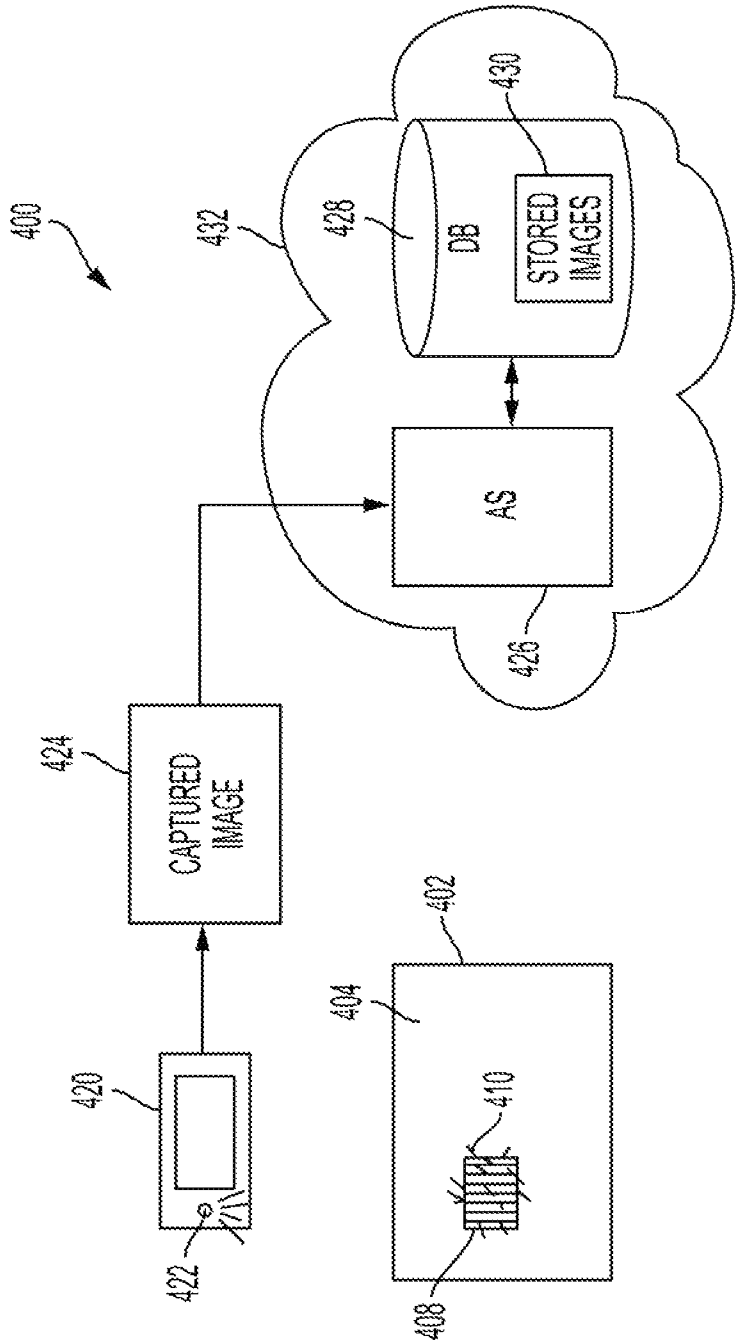
400
432
428
DB
STORED IMAGES
430
AS
426
CAPTURED IMAGE
424
420
422
402
404
410
408

FIG. 4

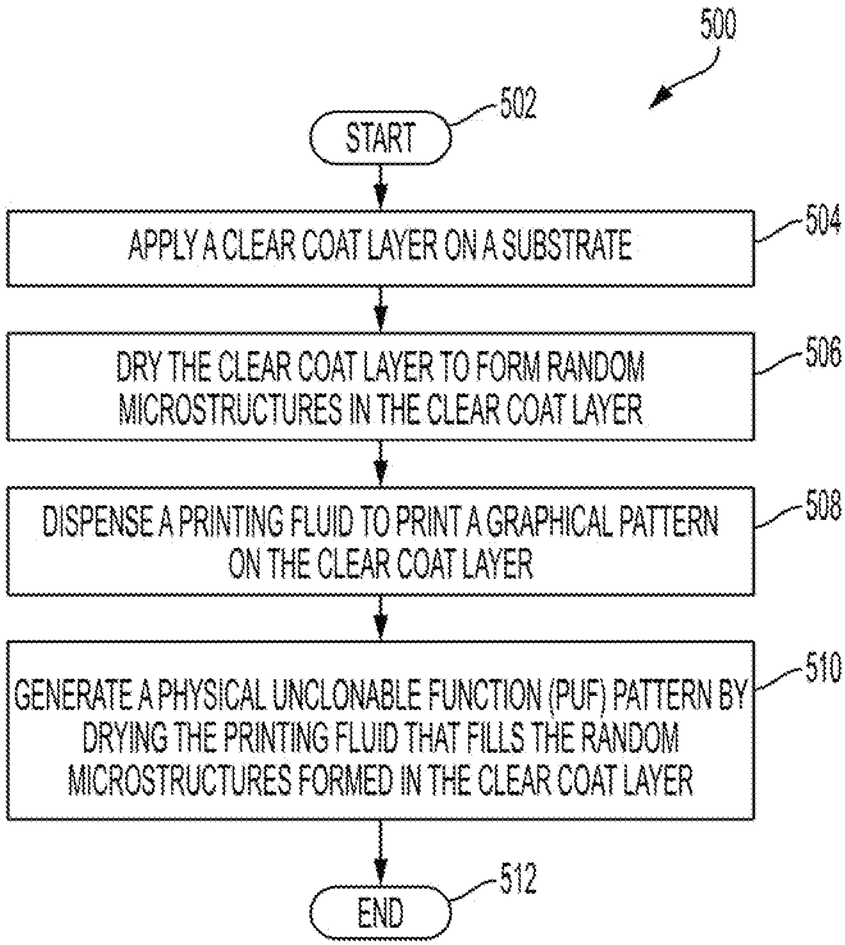
500
502
START
504
APPLY A CLEAR COAT LAYER ON A SUBSTRATE
506
DRY THE CLEAR COAT LAYER TO FORM RANDOM MICROSTRUCTURES IN THE CLEAR COAT LAYER
508
DISPENSE A PRINTING FLUID TO PRINT A GRAPHICAL PATTERN ON THE CLEAR COAT LAYER
510
GENERATE A PHYSICAL UNCLONABLE FUNCTION (PUF) PATTERN BY DRYING THE PRINTING FLUID THAT FILLS THE RANDOM MICROSTRUCTURES FORMED IN THE CLEAR COAT LAYER
512
END

FIG. 5

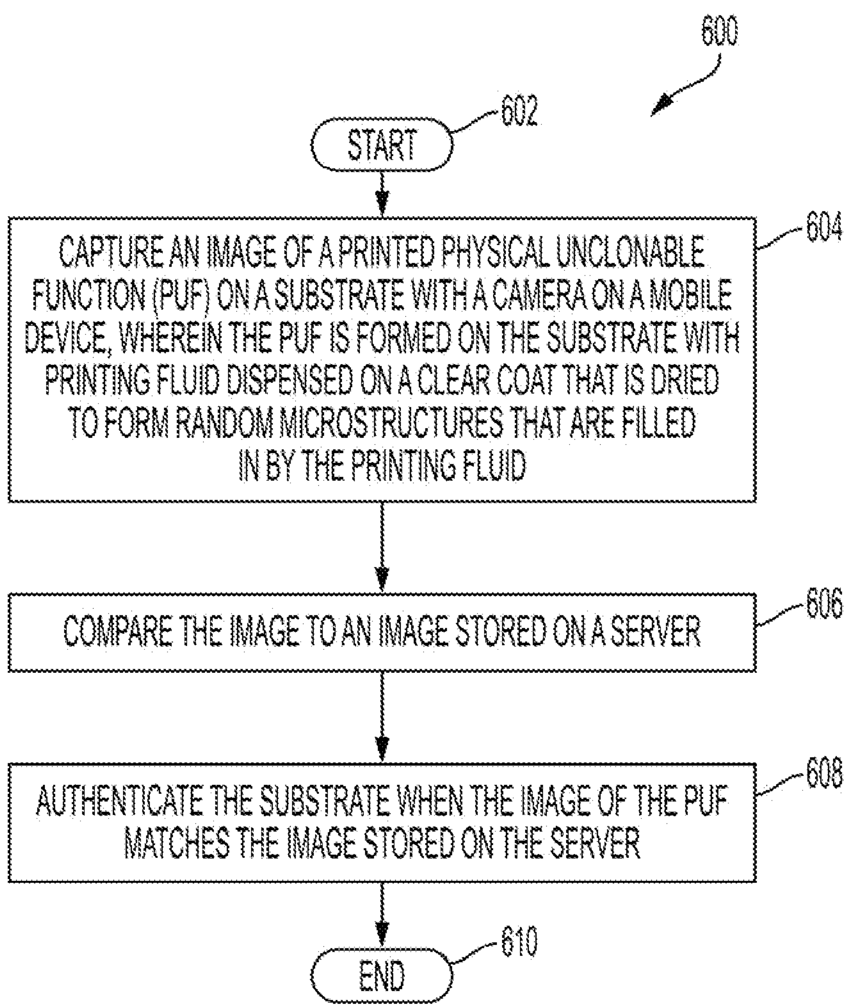
600
START
602
CAPTURE AN IMAGE OF A PRINTED PHYSICAL UNCLONABLE FUNCTION (PUF) ON A SUBSTRATE WITH A CAMERA ON A MOBILE DEVICE, WHEREIN THE PUF IS FORMED ON THE SUBSTRATE WITH PRINTING FLUID DISPENSED ON A CLEAR COAT THAT IS DRIED TO FORM RANDOM MICROSTRUCTURES THAT ARE FILLED IN BY THE PRINTING FLUID
604
COMPARE THE IMAGE TO AN IMAGE STORED ON A SERVER
606
AUTHENTICATE THE SUBSTRATE WHEN THE IMAGE OF THE PUF MATCHES THE IMAGE STORED ON THE SERVER
608
END
610

FIG. 6

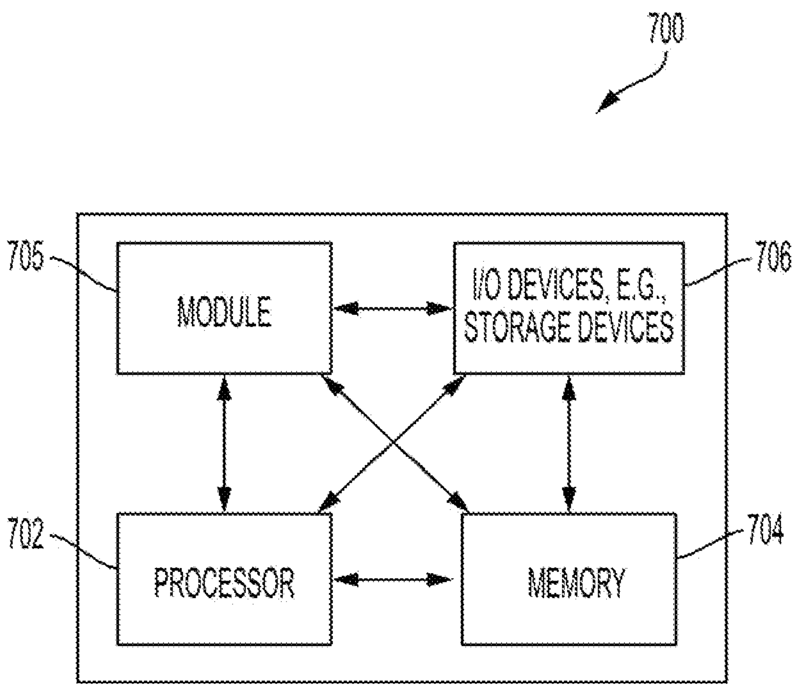
700
705
MODULE
I/O DEVICES, E.G., STORAGE DEVICES
706
702
PROCESSOR
MEMORY
704

FIG. 7

PRINTED PHYSICAL UNCLONABLE FUNCTION PATTERNS

The present disclosure relates generally to anti-counterfeiting, and relates more particularly to a method and apparatus to print physical unclonable function patterns.

BACKGROUND

Physical unclonable functions (PUFs) are unique random physical patterns that can be used for anti-counterfeiting. PUFs can be very difficult and costly to duplicate and may be fabricated by a stochastic process that affords a large number of robust tags. The PUF patterns can be designed to be readable with appropriate analytical tools. The PUF patterns can be recorded and stored for verification. A PUF can be used to prevent counterfeiting, prevent substitution of parts in an assembly, ensure proper custodianship, serve as an uncopiable digital signature, and the like.

Current methods to generate PUFs can be expensive to produce and not economically viable for wide use. Some examples of these expensive methods may include PUFs that are integrated with unique markers that carry a special optical signature (e.g., absorption or luminescence at a certain wavelength or combination of wavelengths), or creation of a random distribution of nanostructures (e.g., nanoparticles, quantum dots, or self-assembly molecules). In addition, detection of these types of PUFs may require specialized analytical equipment, which is not easily accessible to distributors and end-users.

SUMMARY

According to aspects illustrated herein, there are provided a method and a non-transitory computer readable medium for printing a physical unclonable function (PUF). One disclosed feature of the embodiments is a method that comprises applying a clear coat layer on a substrate, drying the clear coat layer to form random microstructures in the clear coat layer, dispensing a printing fluid to print a graphical pattern on the clear coat layer, and generating a physical unclonable function (PUF) pattern by drying the printing fluid that fills the random microstructures formed in the clear coat layer.

Another disclosed feature of the embodiments is a non-transitory computer-readable medium having stored thereon a plurality of instructions, the plurality of instructions including instructions which, when executed by a processor, cause the processor to perform operations to apply a clear coat layer on a substrate, dry the clear coat layer to form random microstructures in the clear coat layer, dispense a printing fluid to print a graphical pattern on the clear coat layer, and generate a physical unclonable function (PUF) pattern by drying the printing fluid that fills the random microstructures formed in the clear coat layer.

Another disclosed feature is a method for authenticating a PUF that is printed. The method comprises capturing an image of a printed physical unclonable function (PUF) on a substrate with a camera on a mobile device, wherein the PUF is formed on the substrate with printing fluid dispensed on a clear coat that is dried to form random microstructures that are filled in by the printing fluid, comparing the image to an image stored on a server, and authenticating the substrate when the image of the PUF matches the image stored on the server.

BRIEF DESCRIPTION OF THE DRAWINGS

The teaching of the present disclosure can be readily understood by considering the following detailed description in conjunction with the accompanying drawings, in which:

FIG. **1** illustrates a block diagram of an example PUF of the present disclosure;

FIG. **2** illustrates a close up of the PUF of the present disclosure;

FIG. **3** illustrates a block diagram of an example apparatus to generate the PUF of the present disclosure;

FIG. **4** illustrates a block diagram of an example system to authenticate the PUF of the present disclosure;

FIG. **5** illustrates a flow chart of a method for printing a PUF of the present disclosure;

FIG. **6** illustrates a flow chart of a method for authenticating a PUF that is printed of the present disclosure; and

FIG. **7** illustrates a high-level block diagram of an example computer suitable for use in performing the functions described herein.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures.

DETAILED DESCRIPTION

The present disclosure broadly discloses a method and apparatus to print physical unclonable function (PUF) patterns. As discussed above, current methods to generate PUFs can be expensive to produce and not economically viable for wide use. Some examples of these expensive methods may include PUFs that are integrated with unique markers that carry a special optical signature (e.g., absorption or luminescence at a certain wavelength or combination of wavelengths), or creation of a random distribution of nanostructures (e.g., nanoparticles, quantum dots, or self-assembly molecules). In addition, detection of these types of PUFs may require specialized analytical equipment, which is not easily accessible to distributors and end-users.

Some lower cost methods that use printing are available. For example, an ink edge anti-counterfeiting method was developed where blowing and pressing after printing was used to create random structures on the ink edges. However, printing only with ink by itself creates a low resolution that is easier to duplicate, which diminishes the security of the PUF.

Embodiments of the present disclosure provide a printable PUF that is low cost while providing a high resolution that makes it difficult to duplicate. In one embodiment, a primary clear coat may be applied to a substrate. The clear coat may be dried to form random cracks in the coat on the substrate. Ink may be dispensed onto the dried primary clear coat. The ink may fill in the random cracks that are formed in the coat to generate the PUFs.

The PUFs of the present disclosure may also be authenticated using widely available equipment. For example, a camera on a cellphone or mobile device may be used to capture an image of the PUF for authentication. Thus, no special equipment is needed for authenticating the printed PUFs of the present disclosure.

FIG. **1** illustrates an example document **100** that includes a physical unclonable function (PUF) **108** that is generated via a printing process of the present disclosure. In one embodiment, although the PUF **108** is illustrated as being printed on the document **100**, the PUF **108** may be printed on any surface, including a packaging, a part, a surface of a device or housing, and the like.

In one embodiment, the document **100** may include a substrate **102**. The substrate **102** may be paper, cardboard, plastic, or any other type of surface that can receive a clear coat layer **104** and printing fluid used to print a pattern **106**. In one embodiment, the clear coat layer **104** may include a colloidal mixture of a fluid and solid particulates. For example, the fluid may be a solvent or water. The solid particulates may include silica or other types of polymers. In one embodiment, the clear coat layer **104** may also use nanoparticle colloidal mixtures, sol-gel solutions, polymer solutions, polymer blends, and the like.

In one embodiment, the clear coat layer **104** may be a commercially available colloidal mixture of water and silica containing between 30 weight percent to 50 weight percent silica. In one embodiment, the clear coat layer **104** may include 34 weight percent silica. In one embodiment, the clear coat layer **104** may include 50 weight percent silica.

In one embodiment, a printing fluid may be dispensed over the clear coat layer **104** to form the pattern **106** of the PUFs $\mathbf{108}_1$ to $\mathbf{108}_n$ (hereinafter also referred to individually as a PUF **108** or collectively as PUFs **108**). Although the pattern **106** of PUFs **108** is illustrated as a series of dots, it should be noted that any pattern **106** may be printed. For example, the pattern **106** may be a bar code, a quick response (QR) code, or a pattern of different shapes (e.g., square, rectangles, ovals, irregular shapes, and the like).

In one embodiment, any type of clear coat layer **104** may be used that can adhere to the substrate **102**. In one embodiment, any type of printing fluid may be used that is compatible with the clear coat layer **104**. In other words, the printing fluid should be able to adhere to and dry on the clear coat layer **104** to generate the pattern **106**.

In one embodiment, the PUFs **108** may be printed to have a width or diameter **110** as small as 50 microns. Thus, the present methods may be used to print PUFs **108** that are relatively small that can use commercially available compounds. In addition, the PUFs **108** may be analyzed or authenticated using widely available equipment (e.g., cameras on mobile phones). Thus, the methods of the present disclosure provide PUFs **108** that are difficult to counterfeit, while maintaining a relatively low cost to print the PUFs **108**.

FIG. **2** illustrates a close up view of the example PUFs **108**. In one embodiment, the clear coat layer **104** may be dispensed and dried to form random microstructures $\mathbf{110}_1$ to $\mathbf{110}_{11}$ (hereinafter referred to individually as a random microstructure **110** or collectively as microstructures **110**). The random microstructures **110** may be cracks that are formed in the clear coat layer **104** from drying.

In one embodiment, the resolution of the cracks or random microstructures **110** may be controlled by a thickness of the clear coat layer **104**. For example, if the resolution is too high (e.g., a smaller number of large sized microstructures **110**), the random microstructures **110** may be too easily copied via a printing process alone. If the resolution is too low (e.g., a large number of smaller sized microstructures **110**), the random microstructures **110** may be too small to be analyzed with an image captured from a standard red, green, blue (RGB) camera on a mobile device (e.g., a camera on a mobile phone).

In one embodiment, the thickness of the clear coat layer **104** may be controlled by an amount of the clear coat layer **104** that is dispensed via a printhead of a printer. In one embodiment, the thickness of the clear coat layer **104** may be controlled by a spin rate of a spin coating process. For example, the clear coat layer **104** may be spun on to the substrate **102** at between 100 rotations per minute (RPM) to 5000 RPM. In one embodiment, the clear coat layer **104** may be spun on to the substrate **102** at between 500 RPM to 3,000 RPM.

Although a spin coating process is described above, it should be noted that other coating methods may be used. For example, the clear coat layer **104** may be applied using a drawdown coating method, aerosol spraying, and the like.

In one embodiment, the resolution of the random microstructures **110** may be such that the random microstructures **110** have a length **112** and a width **114** of several hundred microns. In one embodiment, the random microstructures **100** may have a length **112** of between 20 to 70 microns and a width **114** of between 3 to 9 microns. In one embodiment, the thickness of the clear coat layer **104** to achieve the desired resolution of the random microstructures **110** may be approximately 5 nanometers (nm) to 100 nm for nanoparticle colloidal coatings described above. The thickness may vary for other types of materials. For example, the thickness of the clear coat layer **104** may be 5 nm to 10 microns for polymer coatings.

In one embodiment, the printing fluid may be dispensed on the clear coat layer **104**, as described above. The printing fluid may fill into the random microstructures **110** formed in the clear coat layer **104**. The image formed by the combination of the printing fluid in the random microstructures **110** and on a particular location of the clear coat layer **104** may form the PUF **108**. In other words, in the example illustrated in FIG. **2**, the PUF $\mathbf{108}_1$ may include the printed dot and the random microstructures $\mathbf{110}_1$ and $\mathbf{110}_2$ that are filled with the printing fluid.

The PUF $\mathbf{108}_2$ may be different from the PUF $\mathbf{108}_1$ as the arrangement and sizes of the random microstructures $\mathbf{110}_3$ and $\mathbf{110}_4$ may be different from arrangement and sizes of the random microstructures $\mathbf{110}_1$ and $\mathbf{110}_2$ of the PUF $\mathbf{108}_1$. The PUF $\mathbf{108}_3$ and the PUF $\mathbf{108}_4$ may also have a unique arrangement, number, and size of random microstructures $\mathbf{110}_5$-$\mathbf{110}_8$ and $\mathbf{110}_8$-$\mathbf{110}_{11}$, respectively. In other words, each PUF **108** in the pattern **106** may be unique or different due to the random microstructures **110** that are generated at different locations along the surface of the clear coat layer **104**.

FIG. **3** illustrates an example apparatus **300** that may be used to print the PUFs **108** of the present disclosure. In one embodiment, the apparatus **300** may be a printer that includes multiple printheads **304** and **306**. The printheads **304** and **306** may be used to dispense different fluids. For example, a storage container **308** may store clear coat that is dispensed via the printhead **304**. A storage container **310** may store printing fluid that is dispensed via the printhead **306**.

In one embodiment, a processor **302** may be communicatively coupled to the printheads **304** and **306** to control dispensing of the clear coat and the printing fluid. In one embodiment, the substrate **102** may be passed below the printheads **304** and **306** or the printheads **304** and **306** may be moved over the substrate **102**.

In one embodiment, the processor **302** may control the printhead **304** to dispense the clear coat to form the clear coat layer **104** on the substrate **102**. The clear coat may be dispensed to form a desired thickness of the clear coat layer **104**, as described above. The printhead **304** may make multiple passes over the substrate **102** to dispense the clear coat.

The substrate **102** with the clear coat layer **104** may be moved to a drying apparatus, oven, or air dried to dry the clear coat layer **104**. Drying the clear coat layer **104** may generate the random microstructures **110** in the clear coat layer **104**.

The substrate **102** may be placed below the printheads **304** and **306** after the clear coat layer **104** is dried. The processor **302** may then control the printhead **306** to dispense the print fluid to print the pattern **106** on the clear coat layer **104**. The printing fluid may fill the random microstructures **110** around the locations where the printing fluid is dispensed. The printing fluid may then be dried to form the PUFs **108**.

It should be noted that the apparatus **300** has been simplified for ease of explanation and may include additional components which are not shown. For example, the apparatus **300** may include a motor to move the printheads **304** and **306**, a memory to store instructions, a power supply, other electrical components, and the like.

Although FIG. **3** illustrates printing the PUFs **108** with a single printer or apparatus **300**, it should be noted that different devices may be used to print the PUFs **108**. For example, the clear coat layer **104** may be spin coated onto the substrate **102** via a spin coater. In addition, ovens may be used to dry the clear coat layer **104** and the printing fluid that is dispensed.

Examples 1-3 below provide examples with process parameters for printing the PUFs **108** of the present disclosure.

Example 1

A colloidal silica solution of 34 weight percent suspended in deionized water was obtained to form the clear coat layer **104**. The colloidal silica solution was applied to a paper board substrate by spin coating at 500 RPM for 1 minute. The clear coat layer **104** was dried in an oven at 60 degrees Celsius (° C.) for 1 hour. An aqueous graphical ink was used to print a pattern on the dried clear coat layer **104**. A Dimatix DMP2800 printer was used to dispense the ink to produce a 600×600 dots per inch (dpi) pattern with the following conditions: drop mass=4.5 to 4.8 nanograms (ng), drop velocity=6-7 meters per second, frequency=5 kilohertz, printhead temperature=ambient to 40° C., and voltage=16-20 volts. The ink was dried in an oven at 120° C.+ for 10 minutes.

Example 2

A colloidal silica solution of 34 weight percent suspended in deionized water was obtained to form the clear coat layer **104**. The colloidal silica solution was applied to a paper board substrate by spin coating at 3000 RPM for 1 minute. The clear coat layer **104** was dried in an oven at 60 degrees Celsius (° C.) for 1 hour. An aqueous graphical ink was used to print a pattern on the dried clear coat layer **104**. A Dimatix DMP2800 printer was used to dispense the ink to produce a 600×600 dots per inch (dpi) pattern with the following conditions: drop mass=4.5 to 4.8 nanograms (ng), drop velocity=6-7 meters per second, frequency=5 kilohertz, printhead temperature=ambient to 40° C., and voltage=16-20 volts. The ink was dried in an oven at 120° C.+ for 10 minutes.

Example 3

A colloidal silica solution of 50 weight percent suspended in deionized water was obtained to form the clear coat layer **104**. The colloidal silica solution was applied to a paper board substrate by spin coating at 500 RPM for 1 minute. The clear coat layer **104** was dried in an oven at 60 degrees Celsius (° C.) for 1 hour. An aqueous graphical ink was used to print a pattern on the dried clear coat layer **104**. A Dimatix DMP2800 printer was used to dispense the ink to produce a 600×600 dots per inch (dpi) pattern with the following conditions: drop mass=4.5 to 4.8 nanograms (ng), drop velocity=6-7 meters per second, frequency=5 kilohertz, printhead temperature=ambient to 40° C., and voltage=16-20 volts. The ink was dried in an oven at 120° C. for 10 minutes.

The above examples were found to form PUFs **108** with a desired resolution. The random microstructures **110** in the clear coat layer **104** were measured to have a width of between 3-9 microns and a length of 20-70 microns.

FIG. **4** illustrates a block diagram of a system **400** that is used to authenticate the PUFs **108** of the present disclosure. As noted above, the printed PUFs **108** may allow available devices to be used to authenticate the PUFs **108**. In other words, expensive specialized equipment is not needed to authenticate the PUFs **108** of the present disclosure.

In one embodiment, the system **400** may include a mobile device **420** that includes a camera **422**. The mobile device **420** may be a cellphone, mobile telephone, a smart phone, a tablet, a laptop computer, and the like. In other words, any device with an image capturing device may be used to capture an image.

An end user may receive a document printed on the substrate **402** and want to authenticate the document. The end user may capture an image **424** of a PUF **408** printed on a substrate **402**. The PUF **408** may be printed or formed similar to the ways the PUF **108** may be printed or formed, as described above.

In FIG. **4**, the PUF **408** is illustrated as a barcode. As noted above, the PUF **408** may be any pattern (e.g., a barcode, a QR code, a pattern of shapes, and the like). The PUF **408** may include a variety of random microstructures **410** located at different locations and different lines of the barcode. The PUF **408** may be formed by dispensing printing fluid or ink on a dried clear coat layer **404** to fill the random microstructures **410** with the printing fluid.

In one embodiment, images may be captured of the PUF **408** after being printed during production. The images may be saved in a database (DB) **428** of a network **432** as stored images **430**. The network **432** may be an internet protocol (IP) network.

To authenticate the document printed on the substrate **402**, the mobile device **420** may transmit the captured image **424** to an application server (AS) **426** via the network **432**. The AS **426** may access stored images **430** in the DB **428**. The AS **426** may compare the captured image **424** to the stored images **430**. If a match is found, the AS **426** may transmit a notification to the mobile device **420** that the document has been authenticated. If no match is found, the AS **426** may transmit a notification to the mobile device **420** that the document is not authentic. Thus, the printed PUF **408** may allow widely available equipment that is relatively inexpensive to be used to authenticate the printed PUF **408** of the present disclosure.

FIG. **5** illustrates a flow chart of an example method **500** for printing a PUF of the present disclosure. In one embodiment, the method **500** may be performed by the apparatus **300** or by an apparatus such as the apparatus **700** illustrated in FIG. **7** and discussed below.

In one embodiment, the method **500** begins at block **502**. At block **504**, the method **500** applies a clear coat layer on a substrate. The clear coat layer may be any type of colloidal suspension of solid particulates that is compatible with the substrate. For example, the colloidal suspension should be able to adhere to the substrate. An example of the colloidal suspension may include silica particles suspended in deionized water.

In one embodiment, the clear coat layer may be applied via a spin coating process, a drawdown coating method, aerosol spraying, and the like. In one embodiment, the clear coat layer may be applied via a printer. The clear coat layer may be applied to a desired thickness to obtain a desired resolution of microstructures that are formed in the clear coat layer, as described below.

At block **506**, the method **500** dries the clear coat layer to form random microstructures in the clear coat layer. The random microstructures may include micro cracks that are formed in the clear coat layer as the clear coat layer is dried. The random microstructures may have a different shapes, arrangement and sizes. An example desired resolution of the random microstructures may include microstructures that have a width of between 3 to 9 microns and a length of between 20 to 70 microns.

At block **508**, the method **500** dispenses a printing fluid to print a graphical pattern on the clear coat layer. The printing fluid may be an aqueous graphical ink. Any type of ink may be used that is compatible with the clear coat layer and can adhere to the clear coat layer to print a desired pattern of PUFs. The printing fluid may fill into the random microstructures around the locations where the printing fluid is dispensed onto the clear coat layer.

At block **510**, the method **500** generates a physical unclonable function (PUF) pattern by drying the printing fluid that fills the random microstructures formed in the clear coat layer. For example, the printing fluid may be dried, and the resulting image of the printing fluid that is dispensed and the printing fluid in the random microstructures may form the PUF pattern. At block **512**, the method **500** ends.

FIG. **6** illustrates a flow chart of an example method **600** for authenticating a PUF that is printed of the present disclosure. In one embodiment, the method **600** may be performed by the system **400** or by an apparatus such as the apparatus **700** illustrated in FIG. **7** and discussed below.

In one embodiment, the method **600** begins at block **602**. At block **604**, the method **600** captures an image of a printed physical unclonable function (PUF) on a substrate with a camera on a mobile device, wherein the PUF is formed on the substrate with printing fluid dispensed on a clear coat that is dried to form random microstructures that are filled in by the printing fluid. In one embodiment, the mobile device may be a cell phone, a mobile phone, a smart phone, a tablet computer, a laptop computer and the like. In other words, any type of device that has a camera may be used to capture an image of the PUF for authentication.

The printed PUF may be formed via random microstructures formed in the clear coat layer that is dispensed on the substrate. The printing fluid may be dispensed on the clear coat and may fill the random microstructures in the clear coat layer. The resolution of the PUFs may be controlled via the material used for the clear coat and a thickness of the clear coat layer, as described above.

At block **606**, the method **600** compares the image to an image stored on a server. For example, an image of the printed PUF may be captured when the PUF is formed. The image may be stored in a database in a network. The database may be managed by an authentication service or a company that printed the PUF. The image captured by the mobile device may be compared to the stored images in the database to determine if a match is found.

At block **608**, the method **600** authenticates the substrate when the image of the PUF matches the image stored on the server. When a match is found, the substrate may be authenticated. For example, the mobile device that captured the image of the printed PUF may receive a message or notification that the substrate has been authenticated. At block **610**, the method **600** ends.

FIG. **7** depicts a high-level block diagram of a computer that is dedicated to perform the functions described herein. As depicted in FIG. **7**, the computer **700** comprises one or more hardware processor elements **702** (e.g., a central processing unit (CPU), a microprocessor, or a multi-core processor), a memory **704**, e.g., random access memory (RAM) and/or read only memory (ROM), a module **705** for printing a PUF, and various input/output devices **706** (e.g., storage devices, including but not limited to, a tape drive, a floppy drive, a hard disk drive or a compact disk drive, a receiver, a transmitter, a speaker, a display, a speech synthesizer, an output port, an input port and a user input device (such as a keyboard, a keypad, a mouse, a microphone and the like)). Although only one processor element is shown, it should be noted that the computer may employ a plurality of processor elements.

It should be noted that the present disclosure can be implemented in software and/or in a combination of software and hardware, e.g., using application specific integrated circuits (ASIC), a programmable logic array (PLA), including a field-programmable gate array (FPGA), or a state machine deployed on a hardware device, a computer or any other hardware equivalents, e.g., computer readable instructions pertaining to the method(s) discussed above can be used to configure a hardware processor to perform the steps, functions and/or operations of the above disclosed methods. In one embodiment, instructions and data for the present module or process **705** for printing a PUF (e.g., a software program comprising computer-executable instructions) can be loaded into memory **704** and executed by hardware processor element **702** to implement the steps, functions or operations as discussed above. Furthermore, when a hardware processor executes instructions to perform "operations," this could include the hardware processor performing the operations directly and/or facilitating, directing, or cooperating with another hardware device or component (e.g., a co-processor and the like) to perform the operations.

The processor executing the computer readable or software instructions relating to the above described method(s) can be perceived as a programmed processor or a specialized processor. As such, the present module **705** for printing a PUF (including associated data structures) of the present disclosure can be stored on a tangible or physical (broadly non-transitory) computer-readable storage device or medium, e.g., volatile memory, non-volatile memory, ROM memory, RAM memory, magnetic or optical drive, device or diskette and the like. More specifically, the computer-readable storage device may comprise any physical devices that provide the ability to store information such as data and/or instructions to be accessed by a processor or a computing device such as a computer or an application server.

It will be appreciated that variants of the above-disclosed and other features and functions, or alternatives thereof, may be combined into many other different systems or applications. Various presently unforeseen or unanticipated alternatives, modifications, variations, or improvements therein may be subsequently made by those skilled in the art which are also intended to be encompassed by the following claims.

What is claimed is:

1. A method, comprising:

applying a clear coat layer on a substrate;

drying the clear coat layer to form random microstructures in the clear coat layer;

dispensing a printing fluid to print a graphical pattern on the clear coat layer, wherein the graphical pattern comprises a bar code, a quick response code, or a pattern of shapes; and

generating a physical unclonable function (PUF) pattern by drying the printing fluid that fills the random microstructures formed in the clear coat layer.

2. The method of claim **1**, wherein the clear coat layer comprises a colloidal mixture of water and solid particulates.

3. The method of claim **2**, wherein the solid particulates comprise silica in a range of 30 weight percent to 50 weight percent.

4. The method of claim **1**, wherein the applying comprises:

dispensing the clear coat layer using a printhead of a printing apparatus that also dispenses the printing fluid.

5. The method of claim **1**, wherein the applying is performed via a spin coating procedure at between 100 rotations per minute (RPM) to 5000 RPM.

6. The method of claim **1**, wherein the clear coat layer is applied to a desired thickness to form the random microstructures at a desired resolution.

7. The method of claim **6**, wherein the desired thickness comprises 5 nanometers (nm) to 100 nm.

8. The method of claim **1**, wherein the printing fluid comprises an aqueous graphical ink.

9. A non-transitory computer-readable medium storing a plurality of instructions, which when executed by a processor, causes the processor to perform operations, comprising:

applying a clear coat layer on a substrate;

drying the clear coat layer to form random microstructures in the clear coat layer;

dispensing a printing fluid to print a graphical pattern on the clear coat layer, wherein the graphical pattern comprises a bar code, a quick response code, or a pattern of shapes; and

generating a physical unclonable function (PUF) pattern by drying the printing fluid that fills the random microstructures formed in the clear coat layer.

10. The non-transitory computer-readable medium of claim **9**, wherein the clear coat layer comprises a colloidal mixture of water and solid particulates.

11. The non-transitory computer-readable medium of claim **10**, wherein the solid particulates comprise silica in a range of 30 weight percent to 50 weight percent.

12. The non-transitory computer-readable medium of claim **9**, wherein the applying comprises:

dispensing the clear coat layer using a printhead of a printing apparatus that also dispenses the printing fluid.

13. The non-transitory computer-readable medium of claim **9**, wherein the applying is performed via a spin coating procedure at between 100 rotations per minute (RPM) to 5000 RPM.

14. The non-transitory computer-readable medium of claim **9**, wherein the clear coat layer is applied to a desired thickness to form the random microstructures at a desired resolution.

15. The non-transitory computer-readable medium of claim **14**, wherein the desired thickness comprises 5 nanometers (nm) to 100 nm.

16. The non-transitory computer-readable medium of claim **9**, wherein the printing fluid comprises an aqueous graphical ink.

17. A method, comprising:

capturing an image of a printed physical unclonable function (PUF) on a substrate with a camera on a mobile device, wherein the PUF is formed on the substrate with printing fluid dispensed on a clear coat that is dried to form random microstructures that are filled in by the printing fluid, wherein the clear coat comprises a colloidal mixture of water and silica in a range of 30 weight percent to 50 weight percent;

comparing the image of the printed PUF to an image stored on a server; and

authenticating the substrate when the image of the printed PUF matches the image stored on the server.

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